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Monolithic Multi-Colour 40 GHz Mode-Locked Laser Array

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Abstract: The monolithic integration of four 40 GHz multi-colored mode-locked lasers with a 4×1 MMI, four electroabsorption modulators and an SOA has been demonstrated. The shortest pulse widths are between 2.63 and 2.85 ps.

OCIS codes: (140.4050) Mode-locked laser; (140.3290) Laser array; (230.3120) Integrated optics device.

Multi-wavelength mode-locked lasers are ideal candidates for high speed optical sampling, photonic microwave systems and next generation optical communication systems [1, 2]. Compared to their hybrid integrated module counterparts consisting of several discrete devices, monolithically integrated mode-locked distributed Bragg reflector (DBR) laser diode (MLDLD) arrays can potentially reduce system costs by simplifying optical alignment and packaging processes and by improving the energy efficiency by eliminating multiple coupling losses into fibers. In this work, we use simple, flexible and low-cost techniques – surface etched gratings and quantum well intermixing (QWI) – to integrate monolithically four 40 GHz 1.55 µm AlGaInAs/InP mode-locked DBR lasers, four electroabsorption modulators (EAMs), a 4×1 multimode-interference (MMI) coupler, and a semiconductor optical amplifier (SOA). The design of the DBR sections was optimized with third-order surface-etched Bragg gratings, a moderate coupling efficiency ($\kappa \sim 65$/cm), and low absorption and scattering losses [3].

The epitaxial structure and fabrication processes are similar to those described in [4]. The schematic and the dimensions of the device are shown in Fig. 1. The separation between two adjacent lasers was set at 125 µm. The raised cosine S-bends were 1020-µm-long. The MMI coupler was 30 µm-wide and 532 µm-long. The 790 µm-long SOA was designed as a curved waveguide terminating at an angle of 10˚ relative to the normal direction of the facet. The MLDLD has a total length of 1155 µm with a 30 µm-long saturated absorber (SA) section and a 140 µm-long 3rd-order DBR section. The period of the DBR varied from 734 to 740 nm for channel 1 to channel 4 respectively. A slot width of 180 nm was selected as a trade-off between scattering losses, fabrication feasibility and reflectivity [3]. For the designed value of κ, the effective length of the DBR is about 55 µm, therefore the effective cavity length is estimated to be ~1070 µm. This value corresponds to a round-trip frequency of approximately 40 GHz.

Fig. 2 shows the mode-locking maps as a function of the gain current (I_{Gain}) and reverse voltage applied to the SA (V_{SA}) for the four channels. 40 GHz pure mode-locking (PML) characteristics were observed for I_{gain} between 120 mA and 300 mA and for $|V_{SA}| \geq 2.0$ V. We found the pulse widened when the value of I_{Gain} was increased and shortened when the value of $|V_{SA}|$ was increased, with the shortest pulse width lying between 2.63 and 2.85 ps. Adjacent to PML area, regions of ML with self-pulsation (SP) were observed. With $|V_{SA}| < 2.0$ V, incomplete ML (IML), i.e. less than 100% modulation, was observed. The SOA was found to have a negligible effect on the output pulse quality, while increasing the output power.

Fig. 3 shows the measured optical spectra and corresponding autocorrelation traces at an operating point at the right-top corner of Fig. 2. The peak wavelengths from CH1 to CH4 are 1560.77, 1564.02, 1567.86, 1572.76 nm, respectively which are nearly the same as the designed values. The FWHM of the optical spectrum of the four channels are 1.07, 1.51, 1.67, 1.36 nm and the corresponding deconvolved FWHM of the pulse widths are 4.28, 3.58, 3.19, and 3.5 ps assuming a sech^2 pulse shape. The corresponding time-bandwidth products (TBP) are 0.56, 0.66, 0.65, and 0.58. The measured RF frequencies were 38.01, 38.43, 38.57, and 38.43 GHz.

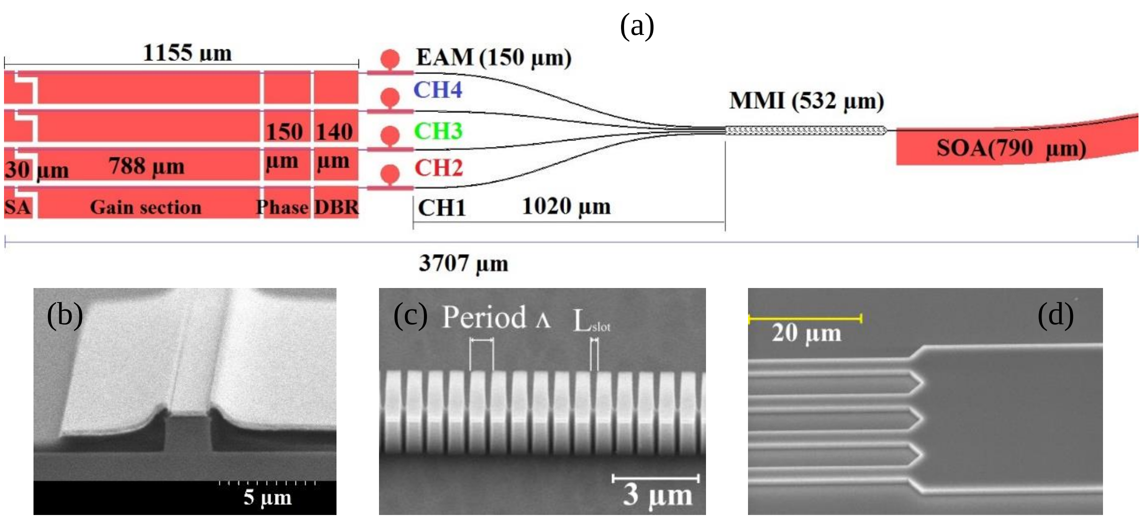

Fig 1. (a) Schematic of the overall 40 GHz DBR mode locked laser array, (b) SEM picture of a cross section of the ridge waveguide, (c) surface-etched third-order gratings, (d) input to MMI coupler section.

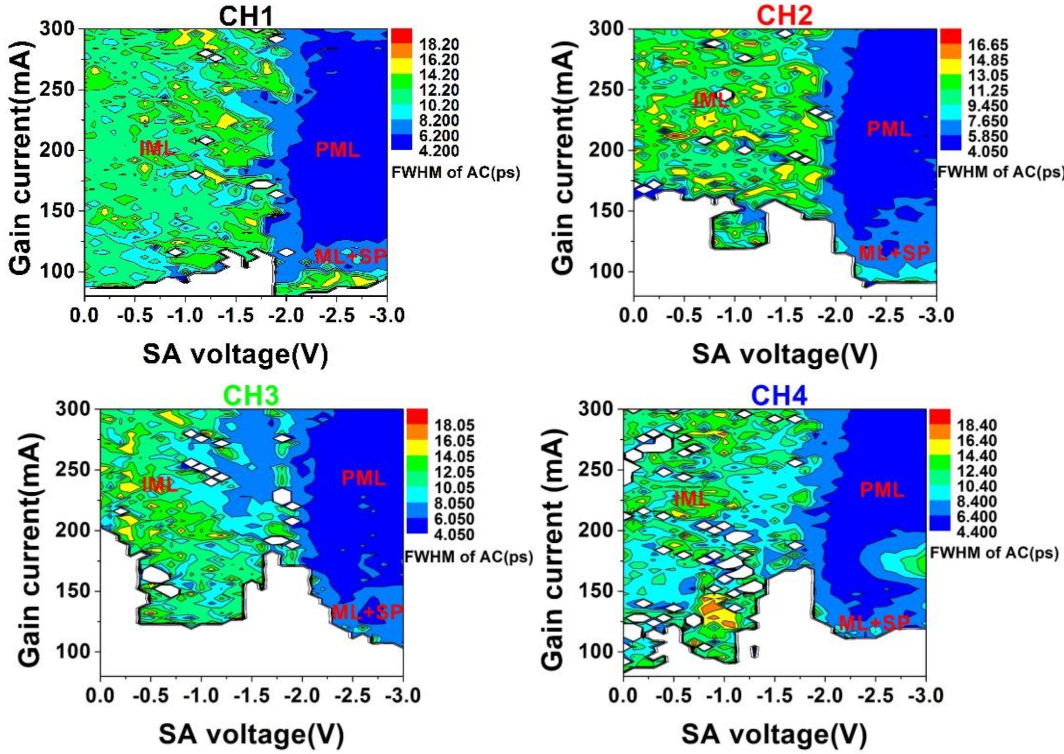

Fig 2. Mode locking map for the four channels with the EAMs floating and SOA current set to 100 mA.

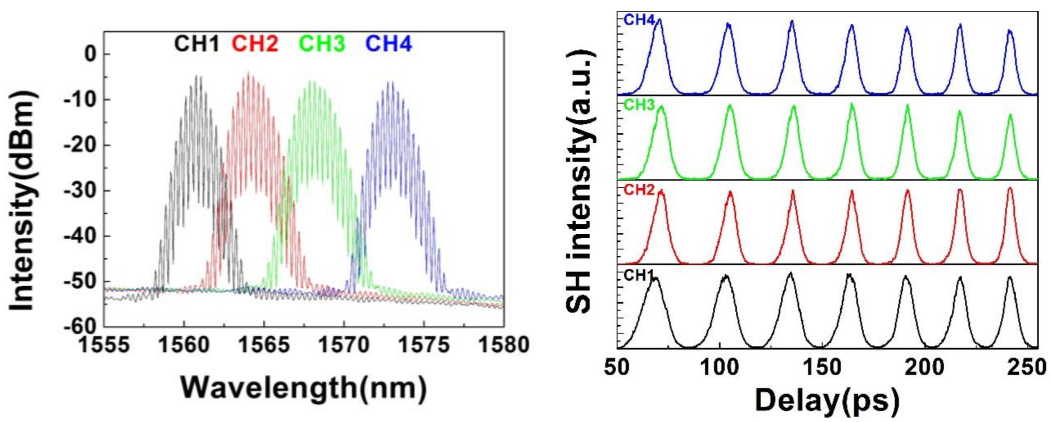

Fig 3. Measured optical spectra (left) and autocorrelation traces (right) of the four channels when V_{SA}= -3V, I_{Gain}=300 mA, I_{SOA}=100 mA and other sections are floating.

Here we note that the SA section can also be used to synchronise the ML frequency to an electrical RF input (hybrid ML). We can use the DBR to tune the peak wavelength and ML frequency and use the EAM for encoding at >10 Gb/s in each channel. The four channels can be operated either individually or simultaneously, and, using either electrical or optical injection, can be easily synchronized to operate at the same F_r of 40 GHz with designated wavelength registration for optical code division multiple access (OCDMA) or optical time division multiple access (OTDMA) systems applications [4].

In conclusion, for the first time an array of four 40 GHz 1.55 μm AlGaInAs/InP mode-locked DBR lasers has been monolithically integrated with individual EAMs, a 4×1 MMI optical combiner, and a curved SOA. Devices were fabricated using simple surface-etched DBR and QWI technologies, which have the advantage of eliminating the crystal re-growth and precision AR coating processes that are required in traditional methods. This device can play a very important role in optical microwave and OCDMA and OTDM systems.

References

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